Information Theory Perspective on Modeling Sustainability

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Abstract

Sustainability requires integrated models for the description of the co-evolving relationships between the economy, society and nature. The paper argues that information theory as a transdisciplinary approach can provide the basis for new theoretical and practical developments in the modeling of sustainability. The methodological problems of its present paradigms (cybernetic, epistemological and pragmatic) however are currently being challenged by the requirements of sustainability. There is a need for a new approach to modeling based on information theory taking into account the assumptions about the nature of information processes, i.e. that they are real, spontaneous and subject to the principle of information relevance. The new sustainability modeling also needs to include intelligence as an information category. A global green information system (GGIS) is a possible example for the application of these concepts.

1. Introduction

In the last 30 years sustainability and sustainable development (which we tend to use interchangeably and define broadly as the process of meeting present and future human needs through an integration of economic prosperity, environmental protection and social advancement [1]) have been shaping as a new area of knowledge, knowledge development and a new profession [1]. There have also been calls for it to develop its methodological approaches and tools, such as sustainability models and indicators, in order for it to respond to the unprecedented challenges posed by the complexity and urgency of the sustainability agenda, including climate change imperatives [2, 3]. Part of the response to the need to improve our understanding of the processes occurring within the ecological environment and human society is the ability to break the silos of disciplinary research. It is essential to look for methodologies and techniques that allow transdisciplinarity and involve ways of studying what is between the disciplines, across the disciplines and beyond the disciplines [4]. According to Nicolescu, transdisciplinarity is interested in the dynamics of simultaneous action of several layers of reality [5] where traditional science approaches are finding it difficult to operate. The sustainability challenge requires exactly this ability to develop knowledge and action at multiple levels while maintaining a holistic perspective of the world and the issues at stake. A major contribution towards this can be made by the tasks of modeling and measuring sustainability [6, 7].

What this paper argues is that information theory, its new paradigms, principles and approaches can form the basis for the development of models for global sustainable development. Its advances coupled with the enormous power of information technology and informatics so far have not been properly used to assist any integrated modeling attempts. On the other hand, the complexity and size of the problems that sustainability poses demand further new developments within information theory and its applications.

Information theory (originated from applied mathematics) requires information to be analyzed as sets (triads) of the system's status related to generation, transmission and reception of information components described as semantics, syntax and pragmatics. The process itself is transformation and transmission of these states while the direction and content of the information process are determined by the information potential of the system [6]. In order to achieve sustainability, there is a need to constantly generate, transmit and receive information about the state of the planet Earth at the local and global level.

The scale and time dimensions of the sustainability problems that span across the globe and beyond the 100-year time horizon require new conceptualization as to how they can be managed. They are unprecedented in at least three aspects: firstly, never before has humanity experienced such profound effects from globalization; secondly, the importance of the human-made world and the laws that govern it, such as the market mechanisms, has grown to become comparable to that of the natural systems; and thirdly, the tools that society and science have developed to handle policy formulation, decision-making and governance (mainly informed by discipline-based assessment methodologies) have been focused on the short to medium term and therefore inadequate from an intergenerational sustainability perspective.

Since the start of the 20^{th} century, globalization has grown to be a distinctive feature of development affecting not only the economy and the cultural fabrics of societies but also the natural environment with the effects of pollution rising to global importance. In fact, sustainable development itself is becoming a "globalizing" phenomenon that reinforces and synchronizes the links between humanity, nature and the economy. Never before has the planet's natural habitat and the human civilization itself been threatened by irreversible anthropogenicly generated changes in its climate triggering weather extremes and calamities beyond previous experiences [8, 9]. An adequate model of sustainable development cannot build on the existing understanding of society and nature as humans have created a "second nature" – the human-made material world which by size and importance has become comparable to the global natural systems. This "second nature" not only acts as a buffer between people and the natural environment but is also ruled by economic laws. Ironically it is now threatening the state of the planet because of the deficiencies in our capability to understand what the consequences of human actions are. Relying on economic rationalism in policy formulation and decision-making has seriously aggravated the problems. For example, we are yet to develop reliable and accurate econometric methods that can handle a time horizon longer than 100 years [10] while the effects of sustainable development (or the lack of it) manifest themselves exactly in a time horizon of this kind. Moreover, sustainability does not exist as an objective reality that can be studied through positivist science [11]. It is a process of constant evolution and adaptation; in fact it represents a co-evolution of nature, humanity and the economy [7] that requires constant monitoring and interpretation in order to find an appropriate intelligent response and guide human actions.

The handling of the scale and nature of these problems can be facilitated by the new advances in information theory coupled with computer power which allow the modeling of information processes occurring during the interactions of intelligent systems. However, this would mean a reconceptualization of the meaning of information and information processes as well as their practical applications which is the focus of the remainder of this paper. The next section outlines the essence of the new information theory paradigm and its qualitative distinctiveness from the cybernetic paradigm. This is followed by a discussion of the nature of information, information processes and information signals before outlining a conceptual model of a basic information process. The relevance of the information conditions are then examined and the concluding sections present some questions and comments on what implications this new conceptualization of information theory have for modeling sustainability.

2. Information theory paradigms

According to Gray, the development of the idea of entropy of random variables and processes provided the beginnings of information theory [12: 17] which is now commonly understood as formalization of processes allowing for data storing and communications, and is associated with the work of Shannon [13], Wiener [14] and Emery [15]. The data carry a particular content or message which is meaningful for the relevant recipient. This approach is typical for cybernetics which until recently was considered to be the general information theory. It is also used in the efforts of cybernetics to create a general model that describes the characteristics and properties of information [16].

The information process is a way to transmit data between systems of the same nature. In essence, in cybernetics the information process is being identified by the generation of a signal which stores and transmits data. Consequently, information is being understood as such a valuable signal content that preserves the properties of the data as a message. In other words, in cybernetics:

- information process ≡ signal generation;
- information ≡ data which contain a message.

As a conceptual and theoretical foundation, the cybernetics paradigm in information theory has been influencing to a great extent the development of informatics and modern computer information systems. Despite this, it is not able to address a range of questions posed by this same information systems development. For example, cybernetics cannot accommodate any issues that relate to the nature of the data, namely their meaning.

Understanding the nature of information as semantics is a crucial paradigm within cognition theory [17], which broadly defines information processes as reflected varieties of objects in people's consciousness. This approach associates information with the psychological processes of cognition and represents the basis of knowledge. By emphasizing the intellectual aspect of information and with its increasing importance in the age of global informatization, this approach becomes essential for the further development of information theory. It is also supported by advances in the understanding of the cognition process coming from areas such as neurophysiology and psychology as well as in the efforts to create artificial intelligence and knowledge-based computer information systems [18]. This approach is best described as the cognitive paradigm in information theory as it equates information with new knowledge that is being generated during the cognitive process. It can be represented as follows:

- information process ≡ cognitive process
- information ≡ new knowledge.

This new information paradigm treats information as a completely different phenomenon to the cybernetics' concept. Firstly, instead of a focus on the objective, entirely physical nature of the signal generation, the centre of attention is placed on the subjective cognitive aspect of information. Hence, this is a new semantic interpretation of information. Secondly, information processes become epistemological which narrows down their scope to a certain type of psychological processes.

Both, the cybernetic and cognitive paradigms within information theory interpret information processes as a conceptual basis for modeling of the main characteristics of information as a phenomenon. The models that they generate are fundamentally different and of vastly different explanatory power.

Informatics and the development of computer-based information systems use a more practical approach towards the problems of information theory. It looks at information processes mainly as the activities that provide information for management together with the technologies that allow its effectiveness. Informatics as a science builds on the cybernetics' paradigm of information theory and extends it to include the pragmatic aspects of information, but does not distinguish between data and information. On the other hand, similarly to the cognitive paradigm it does include the human element as a required element in the information process. For example, the definition provided for business information systems refers to information as data that are being processed for a particular purpose [19]. This pragmatic information theory paradigm can be described as follows:

- information process ≡ storage, transmission and processing of data
- information ≡ data that are being processed for a particular purpose.

The above three information paradigms reveal different aspects of information but do not allow to be integrated in order to fully understand its value and role. It is also difficult to capture the concept of new knowledge generation particularly for the purpose of modeling and managing sustainable development.

They all however imply transdisciplinarity as they deal with crossing between different systems and states and the generation of a holistic true picture of reality (as distinctive, for example, to fragmenting the reality or studying only a particular set of its properties). In order to further explore the modeling power of information theory and its relevance to sustainability, we examine three basic information principles, namely: information determinism, the immateriality of information as such and the axiom of the twins before turning onto outlining the rules that define the information relevance of systems.

3. Information determinism

The first information principle is that of information determinism, namely that it is only the information process that determines the existence of information [20]. In other words, information is being generated and exists only within the information process; it does not exist by itself outside (before or after) the information process; moreover the latter defines its time and place of origin as well as its characteristics. Hence, the nature, properties and conditions associated with the information process establish what information is being generated.

Information determinism has three implications:

• Firstly, there is a cause-effect relationship between the information process (cause) and information (effect). This helps distinguish information from data which can exist after the information process has terminated. In fact, data represent the material trace from an information process as they preserve the features of the events and relationships that have formed them. In this sense, information is distinct not just from data but also from other similar notions, such as meaning [21], messages, records, facts as well as knowledge. While information is determined by the information process only and in this sense exists objectively, the value of the latter is linked to the role of the cognitive process and the subjects involved in it.

• Secondly, the ontological interpretation of information allows a clear distinction between knowledge and information: (1) information can be meaningful and exist independently, in some cases outside any particular cognitive interpretation, while knowledge is the direct product of a cognitive process; and (2) there is no information outside an information process, while knowledge exists outside or independently of any information process as a characteristic of cognitive subjects. Consequently knowledge exists prior to, during and post any information process and can only be facilitated through this information process. In this sense, knowledge is independent from the information processes despite the fact that there may be some common qualitative properties such as syntactic, semantic or pragmatic.

• Thirdly, information is dynamic, spontaneous and provides the link between cognitive subjects. Knowledge, data, facts, messages, records or notes are by comparison more static and also relatively secluded within the cognitive processes that have created them.

Information determinism has another aspect which needs to be pointed out. Similarly to the fact that information exists only within the information process, information processes themselves exist solely because of their capacity to transmit information. There can be many qualitatively different information processes in relation to how information is received, stored, transmitted, processed and enriched (and this is the subject of study of informatics) but the two main implications from information determinism are:

• Information processes can exist naturally and objectively within a properly created environment and independently of any observers; and

• Information processes represent information and its properties; in fact, information represents the quantitative-qualitative content of the information process.

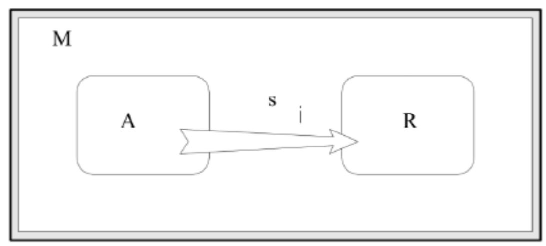
The main implication from the first information principle in relation to the modeling of sustainability is that there can be objective information processes happening in nature and within human society that can clearly indicate the changes that are occurring.

4. Immateriality of information

As an interaction between particular systems, the components of the information process can be basically represented as (see Figure 1): the system which activates the information process (A) and acts upon another system which is the recipient in the information process (R) through the physical impact of a signal (s) within an information process medium (M). The nature of the interaction depends on the properties of the participating components and the functional links between them. This also determines the features of the information process and information.

The second information principle states that information is immaterial, i.e. it does not exist in a material or energy form. There is no such a thing as an infotron or an information field; instead information is the outcome from the material and/or energy exchange or interactions between the participants in the information process (systems A and R on Figure 1). These interactions can be mechanical, physical, biological, social etc. and represent the process of signal transmission. Hence from a practical point of view, it is the signal, and not information, that determines a good information process. This is also the area where information technology has been so successful, namely in signal processing (e.g. [22]).

From an information theory point of view, the transmission of information in the material world is a material or energy exchange dependent on the actual quantitative, qualitative and/or structural disparity between the two interacting systems (A and R). The only time such an exchange would not occur would be if the two systems completely coincide or are completely identical, which in reality is mainly a theoretical probability because of the endless variety of differences between two real systems. Hence for an information process to occur, there is a need for asymmetry between the two basic systems (i.e. the asymmetry requirement in the information process).



Notes: A – activating system; R – recipient system; M – information process medium; s – signal and i – information

Figure 1. Basic information process

The main implication from the second information principle for the modeling of sustainability is that if there is asymmetry between the systems, there will be information processes as well as information. It is also important to emphasize that such signal transmission and information interactions within a situation of asymmetry do not require the participation of cognitive subjects or any processes of conceptualization, studying or making use of the generated information.

Different information processes can exist in parallel or by complementing one another but the focus of the next section is on the basic elementary information process which is described by the axiom of the twins.

5. Axiom of the twins

The basic information process (BIP) is presented in Figure 1. The following assumptions apply for its components:

(1) M (the information process medium) contains A

(the activating system) and R (the recipient system) and has no other sub-components than A and R; M is an isolated environment which is not exposed to outside forces and actions; M is also a homogenous information medium which implies that A and R are systems with identical composition and structure but can differ in state;

(2) s (the signal) is a physical process, the material carrier of BIP which has a material impact on R.

Under the above assumptions, a basic information process occurs that leads to a complete equalization of the states of A and R. In other words, in a closed homogenous environment, each information process starts with the above two conditions and is accomplished when there is identity between A and R. We refer to this as the axiom of the twins or the third information principle. A free interpretation of this axiom concurs with the findings of the statistical theory of quantitative information. For example, if we define the relative diversity of the medium M as a measure of difference or lack of identity between A and R, then BIP triggers an increase in the order and coordination in the behavior of R in relation to A. As a result, BIP reduces the relative diversity of M, which upon its completion no longer exists. The negentropy or the level of determination of the medium during the process of information transmission is related to reduction in the relative diversity, and in fact it increases. To a certain degree, this means reduction of the indeterminism and independence in the behaviour of R in relation to A.

The axiom of the twins represents only one particular simplified case of information processes when M is homogenous and closed with only two interacting (one activating and one recipient) systems. It is based on the following principles:

- Principle of the necessary condition – the necessary condition for the changes in the recipient system as a result of the information process is the information process itself. The changes in the state and behavior of the recipient in BIP, which are an indication for the existence of an information process, are caused by this process;
- Principle of determinism – there is always an information process when certain prerequisites (preconditions) and conditions exist; in the case of BIP, this implies the above-mentioned assumptions.
- Principle of identification – the changes in the state and behavior of the recipient system during the information interaction represent a transmission (translation) and inclusion (internalization) of essential characteristics of the activating into the recipient system;
- Principle of infinity – each BIP takes place until that moment in time when the conditions of the axiom of the twins are fulfilled.

There are some immediate practical consequences from the BIP postulation. They are particularly relevant to modeling sustainability in its attempts to provide an accurate picture of the planet. The first relates to the predictability of the information process and is formulated along the lines that the information process can be predictable. In other words, each BIP takes place exactly in the same way in its medium if the starting conditions are fulfilled. This implies that the content and quality of the information depend entirely on the starting conditions of the information process. Similarly, in nature information processes are also predictable or determined according to the conditions that exist or have been formed. If the conditions are identical or unchanged, the information processes are also unvaried, and vice versa. The second relates to the modeling of the information process. As information processes take place in the same way in identical media, the conditions for closeness and homogeneity of the medium oversimplify the BIP model and limit its applicability for studying real information processes where the information medium is an open and heterogeneous system.

The BIP model however allows us to explore and interpret the processes that occur in the real world. What becomes important is to identify which system is which, namely which plays the role of an activating or recipient system. This cannot be decided within the information process model itself, as it is the nature of the medium, its composition, structure, parameters and state that impact on the information interaction. For example, in a homogeneous medium of physical objects, the energy potential of the components determines which would be the activating or recipient system. In other words, the medium's negentropy, e.g. the difference between the energy potential of A and R as an example of relative difference, is the sufficient condition for the information process to exist. The role-playing in this example is defined by the fact that A has a higher energy potential than R.

A third implication relates to the presence of a signal. The BIP model does not imply the compulsory existence of a signal, although it can be present as a supplementary element. Its function is to be the intermediary in the interaction between A and R. It is nevertheless necessary, when: (1) A and R are placed in time and space in a way that does not allow an immediate interaction and hence, an intermediate carrier is required; and (2) the nature and the complexity of the information process are such that they do not allow for a direct information impact (for example, one of the systems is material and the other an energy field). It is however important to realize that information exchange can occur without a signal, or in other words focusing mainly on the signal as an indicator for information processes can be misleading and leave unnoticed other changes that are occurring. There are other implications, such as homogeneity/ heterogeneity of the information process (discussed in section 6) or the quantity of generated and transmitted information (requiring further investigation). The above three however represent the basics for modeling sustainability.

6. Information relevance

A major challenge in studying sustainability is the implied requirement for a holistic view of the world, which in a positive science tradition we have learned to fragment and analyze as systems of different nature. For example, the approach of geology or biology is applicable only if we are to explore this specific part of nature, namely rocks or living organisms. The issue now is how to cross the boundaries of knowledge between these fields and to understand the interactions that occur not just within but also across them.

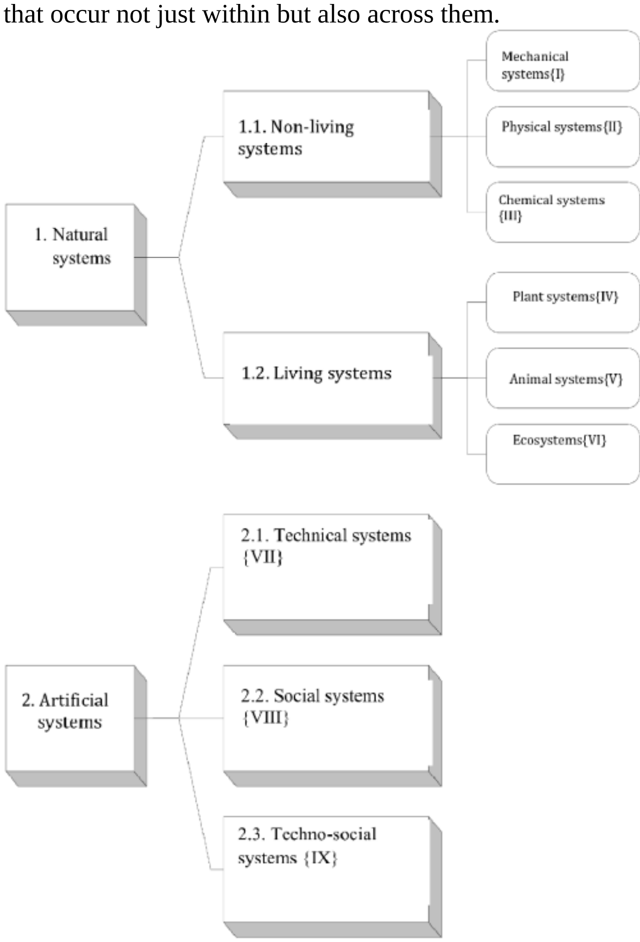


Figure 2. Hierarchy of Earth's systems

Information theory can offer some insights towards such a transdisciplinary approach as it attempts to address the questions related to the nature and characteristics of heterogeneous information processes. Heterogeneity is a systems property which relates to the large variations of structures and properties in nature as well as within human society. There have been numerous attempts of classifying the systems on Earth (e.g. [23, 24]), and Figure 2 is another example of this. They all ignite debates about completeness and the logic of the underlying categorization. Notwithstanding this, the suggested working hierarchy (e.g. {I} to {IX}) presented here follows the approach that the systems at a higher level encompass the systems of a lower order. Each system of a higher order has a substructure of systems of a lower order. For example, a living system in addition to its own structures has mechanical, physical and chemical structures. These substructures can be of the same (e.g. several physical substructures) or different (e.g. a combination of the above) nature.

The artificial systems are of a particular interest in relation to sustainability, as they exist only as a product of human inventiveness and activities, and ironically have paved the road to irreversible climate change consequences if the current trends continue. By definition, the technical systems facilitate the use of resources, be it natural (represented by the application of technologies) or human (represented by the market mechanism or other rules governing relationships between countries and people). They are also a product of the knowledge, experience and skills that humans have accumulated in dealing with the natural world and they directly represent a way of providing for people's needs. The social systems are considered to be a level above the technical systems as they manifest the emergence of new qualities, such as ethics, values, emotions, intuition, empathy or spirituality which are at the core of the whole dilemma as to why we as humans should care about future generations [25]. The techno-social systems are the top of the hierarchical ladder because of the role played by information and intellect. They manifest the quality and actions of intelligent agents, be it human or non-human [26], or combined human–no-human intelligence.

The relative independence of the substructures in a complex system allows for the principle of superposition to be applied in the case of information processes in heterogeneous systems. As an approximation, each heterogeneous information process can be considered a superposition of homogeneous information processes. For example, if the participants in an information process are a social (S) and a living (L) system, then this process can be understood as a parallel occurrence of several homogeneous information processes at the chemical, physical or mechanical level (see Figure 3).

If the conditions for information processes exist for the respective substructures, then information transmission could be occurring in one of three ways: (1) S ⇒ L; (2) L ⇒ S or (3) different directions for the various information sub-processes (which would then require for these sub-processes to be considered as heterogeneous and formed of homogeneous unidirectional processes).

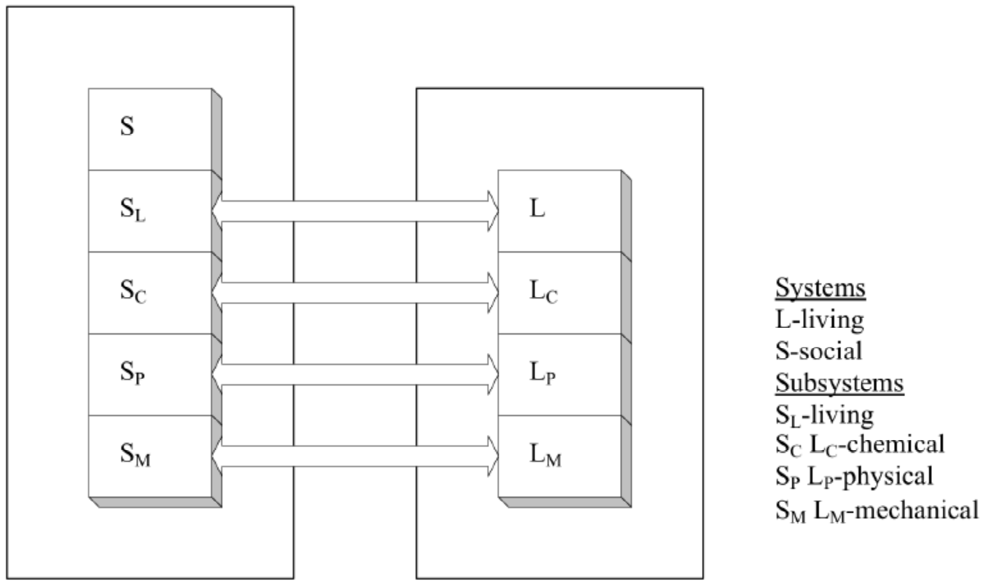


Figure 3. Heterogeneous information process

The following three rules and three conditions can be formulated in relation to the nature and origin of information:

R1: Rule of the semantic minimum – in a heterogeneous information process, the semantics of information (Se) is determined by the nature of the lowest hierarchical (e.g. {I}–{IX}) system;

R2: Rule of the pragmatic maximum – in a heterogeneous information process, the pragmatics of information (Pr) is determined by the nature of the highest hierarchical (e.g. {I}–{IX}) system;

R3: In a heterogeneous information process, Se and Pr are independent from the nature of the signal (s).

In their entirety, rules R1–R3 represent the Law of Information Relevance for the systems participating in the information processes. They can be of assistance in understanding the information required for the development of models for sustainability.

7. Information theory and sustainability

This section introduces co-evolution as the underlying concept for understanding sustainability and provides an example for an information theory perspective on its modeling through the potential power of a Global Green Information System (GGIS).

7.1. Co-evolution and sustainability

In order to model sustainability, there is a need for the global systems to be represented. Following the systems classification from Figure 2, Figure 4 emphasizes the three main active components, namely the natural environment (N, represented as natural systems in Figure 2), the economy (E, represented as the technical systems in Figure 2) and humanity (H, represented as the social systems in Figure 2). The missing systems from the hierarchy are the techno-social systems. In fact, the main task that we have at the moment in order to achieve sustainability is to create the conditions for the techno-social systems to start functioning and manifesting their new emerging intellectual properties.

It appears that an attempt to coordinate an arrangement of the systems following Figure 3 with the systems represented in the global model of sustainability (Figure 4) would face unexplored territory in information theory. For example, we are not aware of acceptable interpretation of the notion of intelligence as well as intelligent systems as information categories. The modeling of sustainability poses new challenges to information theory which it will have to resolve not only from this perspective but also on a more general basis.

In addition, the current co-evolution of nature, humanity and economy [7] raises a series of questions that recent information theory will need to address:

1. What is the nature of the interactions between the three global systems and how can they be modeled?

The processes of interaction within each system can be modeled with the already existing tools, such as pure economics and econometrics for the economic system, environmental, physical and biometric models for the natural environment, or sociological, political and sociometric models for the human system. The information processes that take place within these individual systems in many ways are much simpler as they rely on relatively homogenous media. However, the modeling of the meta-system would require a model of a completely different nature which information theory can inform.

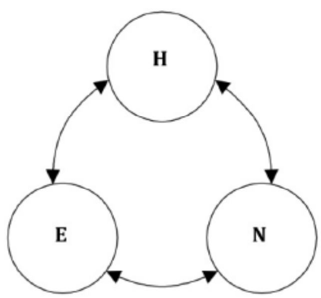


Figure 4. Co-evolution of the global systems

There is enough evidence that the three global systems are constantly changing and shaping as a result of multiple interactions. They are in fact co-evolving and a model of this global sustainable development system (GS) would be that of a meta-system ① which is in a state of dynamic balance (⊕):

$$\mathbf{GS = H \oplus E \oplus N} \qquad ①$$

where H is humanity; E –global economy and N – the global natural environment (see also Figure 4).

These three completely heterogeneous systems, which differ in nature, complexity and composition, do not allow an integrated physical modeling but would require modeling that is based on analogy. This is exactly the essence of information modeling. What is the ability of the current models of information processes (including the insights provided by BIP) to develop such models? Sustainability will require the dynamic balance processes (⊕ in equation ①) to be deciphered in adequate information models.

2. What are the main characteristics of the information generated through the models of sustainable development?

If we agree that the sustainability models will have to be <*Dynamic*-t_d, *Global*-s^g, *General*-r^C> [7], then what type of information would be relevant to represent the co-evolutionary processes? In other words, what are the principles and laws of information relevance that apply to the interactions of co-evolving heterogeneous systems as represented in ①?

3. If information processes arise spontaneously, how can they be understood and managed?

As information processes are distinctively different from cognitive processes, and information is different from knowledge, the role of intelligence and intelligent systems becomes extremely important. The intelligent behavior of each global system as well as that of the meta-system will be the outcome of addressing and resolving a range of issues that are constantly emerging. This will necessitate:

- New knowledge to be constantly generated or acquired;
- A picture of the state of the world which adequately represents in each instance the behavior of the activating system and the information medium. The recipient system will be building this picture based on existing knowledge or will rely on other interpretations;
- A model of the information interactions which would need real information processes and the participation of intelligent and cognitive subjects.

This will require the intellect to be in a position to grasp the changes occurring in the meta-system and act adequately to the demands that they generate.

The answers to these raised profound questions call for more advances in information theory and information modeling. Despite the challenges they pose, there is evidence that we can expect further progress in the future. The sustainability imperatives are likely to be taken seriously by information theory as the hope for the future of this planet lies in the claims of intelligence that humanity has.

7.2. Global Green Information System (GGIS)

The insights from the information theory perspectives on sustainability allow us to conclude that there are information processes that occur independently from the human intellect (which humans have been trying to capture through the knowledge and tools available from within the three global systems) and that a new approach is possible to transcend the boundaries between the three heterogeneous systems. In fact, it is the first time in the history of humanity that computer power permits the building of a global virtual (e.g. GIS-based) model of the planet Earth based on information theory. If developed, such a model would allow not just forecasting and prediction but also scenario building and trajectory projections within the probability spaces for the future. It will represent a global virtual reality that could be studied, analyzed, explored and hopefully properly understood.

A possible example for the application of the information theory to modeling sustainability is the opportunity to establish a Global Green Information System (GGIS) at the core of which would sit such a global virtual model of the planet. This GGIS however will need to incorporate other functions that allow proper decision-making and governance of the processes on Earth. Meadows et al. [27] emphasize that despite their knowledge generation power, information and information flow are only one leverage point to intervene in a system to restore its sustainability. The information from the global virtual model will be put into use according to people's value systems and available decision-making systems and processes.

Therefore the GGIS should not only collect, store and transmit sustainability information across the globe but should also facilitate decision-making. The ability to provide a space for deliberation and exchange of ideas, understanding, perspectives and worldviews [28] should be an essential part of GGIS. It is crucial that such an exchange occur in a non-hierarchical environment where there is full awareness that the tasks of achieving and maintaining sustainability are not only shared but cannot be achieved on an individual basis and without cooperation.

It is difficult to speculate on the timing for such a GGIS to be created but it is clear that the information theory has a long way to go to be able to inform tasks of this scale. The presented discussion raises more issues than it solves but all of them can form a methodological framework for further work.

8. Conclusion

According to Clark et al. [29: 20], "(i)nformation is central to guidance, and guidance for a sustainability transition needs information on both where we want to go as well as how well we are doing at getting there". What we argued is that information can only provide such a guidance and inform a transition if proper information processes exist that are made meaningful through the power of intelligent systems and actors.

The nature of mathematical, information and computer modeling implies the use of formal descriptions. They are analogous abstractions of the reality as distinct to physical or social models based on the nature of things. Information models that use information processes based on some formalization of real-world behavior require good understanding and clear definition of the objects that act as agents for these information processes. The methodological problems of the current information theory paradigms, cybernetic, epistemological and pragmatic, are being challenged by the requirements for a transdisciplinary approach to knowledge generation. Hence the modeling for sustainability based on information theory needs to take into account the assumptions about the nature of information processes, namely:

- They are real processes of system interactions;
- They are spontaneous and occur in an environment shaped by the interactions between the system's components;
- They are subject to the law of information relevance, which is based on the system's hierarchy, nature and complexity.

We are yet to see the study of the global processes of sustainable development and their modeling using the information theory. There is a need for a new area which would cover the study, modeling and measuring of sustainability allowing new knowledge to be generated that helps in analyzing current trends, forecasting expected changes and managing in an intelligent way the global system of "humanity–economy–natural environment" for a sustainable development. Hence, this new information modeling for sustainability will also have to include intelligence as an information category.

The issues discussed in this paper together with the put forward example only attempt to search for a new approach toward the sustainability challenge. They also stress the need for global solutions to the global problems we are witnessing now. Globalization is no longer only an ontological category, it has become a theoretical and practical problem that science has to address. From an information theory perspective, it is clear that we do not have the answers yet but we are ready to venture in a new space to look for new ideas.

9. Acknowledgements

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10. References

[1] P.W.G. Newman, "Can the Magic of Sustainability Revive Environmental Professionalism?", in C. Sheldon, (ed.) Environmental Professionalism and Sustainability: Too Important to Get Wrong, Greenleaf Books, London, 2006, pp. 11-24.

[2] S. Faucheux, and M. O'Connor (eds), Valuation for Sustainable Development: Methods and Policy Indicators, Edward Elgar, Cheltenham, UK, 1998.

[3] S. Bell, and S. Morse, Sustainability Indicators: Measuring the Immeasurable?, 2nd edition, Earthscan, London, 2008.

[4] D. Marinova, and N. McGrath, "Transdisciplinarity in Teaching and Learning Sustainability", in G. Banse, I. Hronszky, and G. Nelson (eds) Rationality in an Uncertain World, Edition Sigma, Berlin, 2005, pp. 275-285.

[5] B. Nicolescu, "The Transdisciplinary Evolution of the University Condition for Sustainable Development", presented at the "Universities' Responsibilities to Society", Chulalongkorn University, Bangkok, 1997, http://perso.club-internet.fr/nicol/ciret/bulletin/b12/b12c8.htm (18.06.2009).

[6] V. Todorov, "System Sustainability and Development Sustainability: Modeling Problems (Is E-conometrics of Sustainable Development Possible?)", Management and Sustainable Development, Vol. 18, No. 3-4, 2006, pp. 136-140 (in Bulgarian).

[7] V. Todorov, and D. Marinova, "Sustainometrics: Measuring Sustainability", MODSIM 2009 International Congress on Modelling and Simulation, Modelling and Simulation Society of Australia and New Zealand, Cairns, Australia, 2009, pp. 1223–1229.

[8] Intergovernmental Panel on Climate Change (IPCC), Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, 2007.

[9] S. Schneider, "The Worst-case Scenario", Nature, Vol. 458, pp. 1104-1105, 2009, doi:10.1038/4581104a.

[10] H. Velasco, "Sustainability: The Matter of Time Horizon and Semantic Closure", Ecological Economics, Vol. 65, pp. 167-176, 2008.

[11] B.J. Caldwell, Beyond Positivism: Economic Methodology in the 20th Century, Allen and Unwin, Boston, 1982.

[12] R.M. Gray, Entropy and Information Theory, Springer-Verlag, New York, 2008.

[13] C.E. Shannon, "A Mathematical Theory of Communication", Bell System Technical Journal, Vol. 27, pp. 379-423 and 623-656, 1948.

[14] N. Wiener, Cybernetics or Control and Communication in the Animal and the Machine, Hermann & Cie Editeurs, Paris, The Technology Press, Cambridge, MA, John Wiley & Sons Inc., New York, 1948.

[15] F.E. Emery, Systems Thinking, Penguin, Harmondsworth, UK, 1969.

[16] T.M. Cover, and J.A. Thomas, Elements of Information Theory, John Wiley and Sons, New York, 2006.

[17] N. Stillings, M. Feinstein, J. Garfield, E, Rissland, D. Rosenbaum, S. Weisler, and L. Baker-Ward, Cognitive Science: An Introduction, MIT Press, Cambridge, MA, 1987.

[18] R. Morris, L. Tarassenko, and M. Kenward, Cognitive Systems – Information Processing Meets Brain Science, Elsevier, Amsterdam, 2006.

[19] G.A. Curtis, and D.C. Cobham, Business Information Systems: Analysis, Design and Practice, 5th edition, Prentice Hall, Harlow, Essex, UK, 2005.

[20] V. Todorov, Artificial Intelligence in Social Research: Theoretical and Methodological Aspects, PhD thesis, Russian Academy of Management, Moscow, 1993 (In Russian).

[21] J.S Bruner, Acts of Meaning, Harvard University Press, Cambridge, MA, 1990.

]22] J.G. Proakis, and D.K. Manolakis, Digital Signal Processing, 4th edition, Prentice Hall, Upper Saddle River, NJ, 2006.

[23] J.G. Miller, and J.L. Miller, "Applications of Living Systems Theory", Systemic Practice and Action Research, Vol. 8, No. 1, pp. 19-45, 1995.

[24] Renewable Energy Information, Earth System Analysis, http://renewenergy.wordpress.com/transition/earth-system-analysis/ (18.06.2009).

[25] Y. Narayanan, In a City Like Delhi: Sustainability and Spirituality, PhD thesis, Murdoch University, Perth, Western Australia, 2008.

[26] J. Martin, The Meaning of the 21st Century, Riverhead Penguin, New York, 2007.

[27] D. Meadows, D, Meadows, and R. Randers, Beyond the Limits: Confronting Global Collapse, Envisioning a Sustainable Future, Chelsea Green Publishing, Post Mills, VT, 1992.

[28] J.M. Pope, A. Morrison-Saunders, and D. D. Annandale, "Applying Sustainability Assessment Models", Impact Assessment and Project Appraisal, 2005, Vol. 23, pp. 293–302.

[29] W.C. Clark, P.J. Crutzen, and H.J. Schellnhuber, "Science for Global Sustainability: Toward a New Paradigm", in H.J. Schellnhuber, P.J. Crutzen, W.C. Clark, M. Claussen and H. Held (eds) Earth System Analysis for Sustainability, MIT Press, Cambridge, MA, 2004.